TRIAXIAL COMPRESSION TESTING OF MULTICOMPONENT GEOMATERIALS FROM QUARTZ-POOR (SYENITIC) SYSTEMS

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Abstract

This paper focuses on mafic microgranular enclaves enclosed in quartz-poor igneous rocks and their effect on strength properties of the rock massif. The study examines host rock–enclave multicomponent geomaterials from enclave-bearing syenitic rocks from the Třebíč Massif exposed in the Královec quarry near Jaroměřice nad Rokytnou in the Czech Republic. A series of laboratory tests were performed to describe strength properties of individual constituents of the multicomponent geomaterials. We mainly focused on triaxial compression tests, however, rebound hardness, uniaxial compressive strength and indirect tensile strength were determined as well. The obtained results indicate that enclaves and even the contact zones between the enclaves and host rocks do not have any negative influence on the rock strength. In contrast, enclaves represent "stress concentrators" within such multicomponent systems. Strength properties of various multicomponent geomaterials are practically an unexplored topic in the field of rocks mechanics and future studies are needed to establish a robust database describing the behaviour of such geocomposites.

Keywords: syenite, mafic microgranular enclave, strength properties

1 INTRODUCTION

Igneous rocks with mafic microgranular enclaves are relatively common worldwide [1–5], and it is therefore usual that we come across these in the construction praxis. Such composite rocks can constitute the environment for engineering works, e.g. underground constructions, notches, foundations of structures, or they can be quarried as raw materials in the form of aggregates or decorative stones for civil engineering projects. Enclave sizes vary in the order of centimetres to metres. Considering their differences with the host rock in modal mineralogy, chemical composition and structure, we can expect enclaves to have different physical and mechanical characteristics. Regarding their variable size and their locally very high abundance, enclaves can constitute a significant component of processed rocks or rock massifs. It is therefore appropriate to investigate their features and their potential impact on the complex behaviour of host rock–enclave multicomponent geomaterials, as suggested in the pilot study of Krmíček (2015) [6].

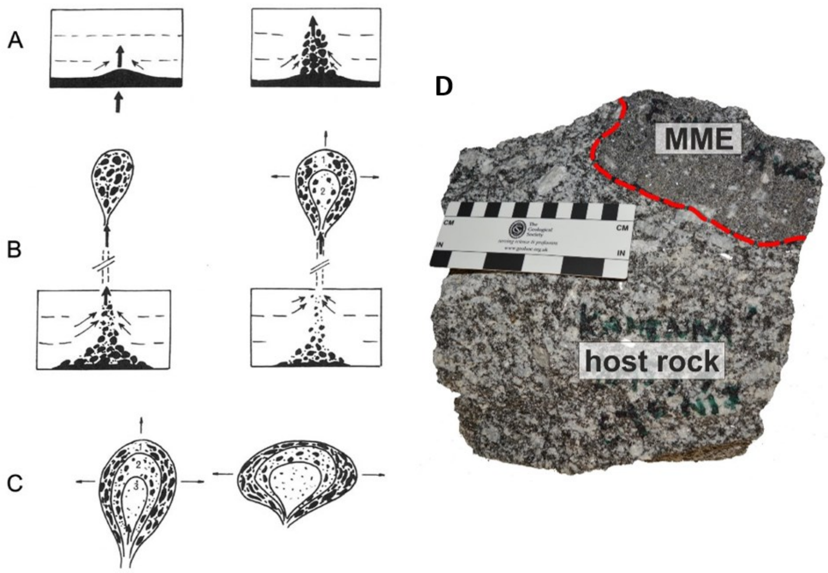

Fig. 1 Formation mechanism of rock massif containing mafic microgranular enclaves. A – intrusion of mafic magma; B – ascent of felsic magma containing "drops" of mafic magma; C – emplacement of zoned massif and its elongation in horizontal direction [11]; D – sample of syenite host rock with mafic microgranular enclave (MME).

Mafic microgranular enclaves form xenoliths of various sizes in syenitic and granitic massifs. The formation of the enclaves is connected with processes of basic (mafic) and acid (felsic) magma mixing [7-10]. Mafic microgranular enclaves represent cooled “drops” of basic magma. Their mafic (dark) colour is caused by higher contents of mafic minerals, and their relatively finer-grained texture is due to faster magma cooling. The enclaves are usually oval shaped and preferentially oriented in the direction of the magma flow. The formation mechanism of the rock massif containing mafic microgranular enclaves is illustrated in Fig. 1.

2 GEOLOGICAL AND PETROGRAPHIC CHARACTERISTICS

The studied rocks were sampled in the Královec quarry near Jaroměřice nad Rokytnou in the southern part of the Třebíč Massif, which is the largest syenite body of Lower Carboniferous age within the Variscan Europe (Fig. 2) [12–14]. The Třebíč Massif is crosscut by a regionally important system of younger mafic dykes emplaced ~330 million years ago [15–16]. Královec is an active quarry specialized in aggregate production for construction uses. The sampled locality was chosen with regard to access to fresh rocks lacking weathering features. The local enclaves can reach sizes of tens of centimetres.

Petrographic examination shows the amphibole-biotite syenite (durbachite) samples contain varying proportions of xenomorphic quartz (< 10 vol. %). Potassium feldspar is the most abundant felsic mineral and typically occurs in the form of strongly zoned phenocryst with characteristic twinning. Within crystals, individual growth zones are outlined by mafic minerals (biotite mica, actinolitic amphibole) that also occur in the matrix.

The studied enclaves are significantly finer-grained compared to their host syenite and contain a large amount of biotite flakes and amphibole needles that are oriented parallel to the contact with the syenite host rock (Fig. 3). Larger xenocrysts of potassium feldspar with corrosion rims are rare in the enclaves. Individual minerals of both syenite and enclave contain abundant inclusions of accessory minerals (zircon, allanite) which are surrounded by characteristic pleochroic halos.

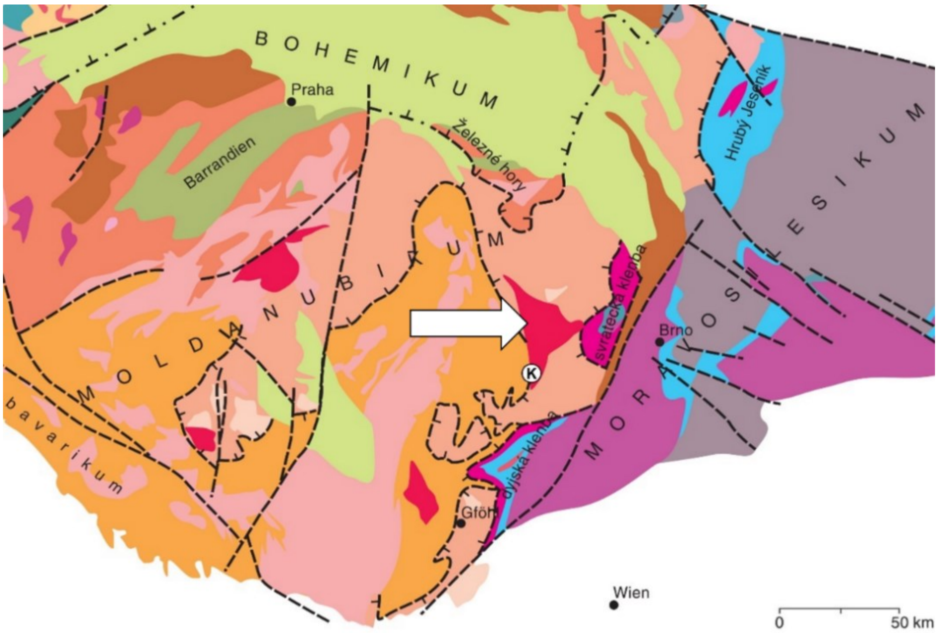

Fig. 2 Simplified geological map showing main geological units in the eastern part of the Bohemian Massif [17]. The arrow points at the syenite body of the Třebíč Massif, K marks the position of the investigated quarry.

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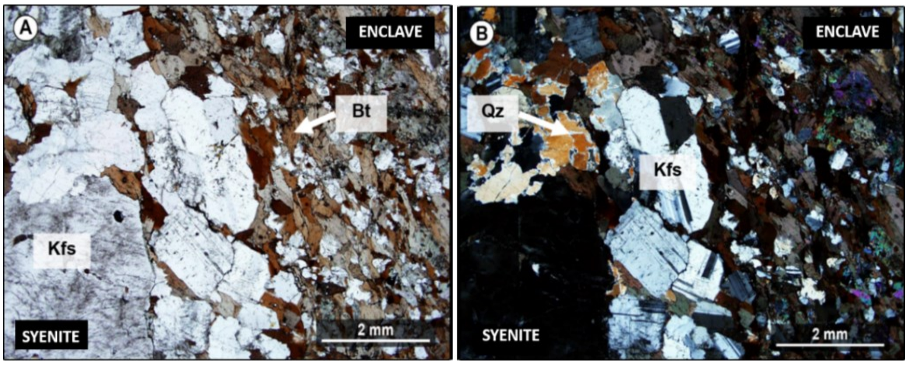

Fig. 3 Photomicrographs of studied multicomponent geomaterials. A – contact between relatively fine-grained enclave and syenite with distinct potassium feldspar (Kfs) and biotite flakes (Bt) flow-directed along the contact (plane-polarised light); B – significant twinning of potassium feldspar (Kfs) and xenomorphic quartz (Qz) (cross-polarized light).

3 METHODS

The laboratory testing of intact rock core specimens made from multicomponent geomaterials was carried out in the AdMaS Centre (Advanced Materials, Structures and Technologies) of the Faculty of Civil Engineering at Brno University of Technology. The laboratory work and data processing were carried out with the help of J. Umlauf (Brno University of Technology). The rebound hardness test was the only one type of tests conducted on rough surfaces of natural rock blocks. For other testing, samples were prepared by core drilling.

The rebound hardness test of the syenite and associated mafic microgranular enclaves was performed using the Schmidt hammer (L-type) method and the results subsequently correlated to the uniaxial compressive strength values. The dry unit weight was determined by the precise measuring and weighing of 6 specimens of each rock type.

The Brazilian test was used to determine the indirect tensile strength. The test was carried out on two samples of syenite and two samples of enclave with a diameter of 54.7 mm and l/d ratio of 1.0. During the test, a load was applied with a rate of 200 N/s.

The uniaxial compression tests were done on 3 multicomponent geomaterial cores with a diameter of 54.7 mm and h/d ratio of 2.0. One sample had a strong predominance of syenite, one had a slight predominance of syenite and one had a strong predominance of enclave. The samples were equipped with two vertical and one horizontal strain gauges (Fig. 4). This allowed us to determine both the Young's modulus and Poisson ratio. The experiment was carried out under stress-controlled conditions with a load rate of 0.5 MPa/s.

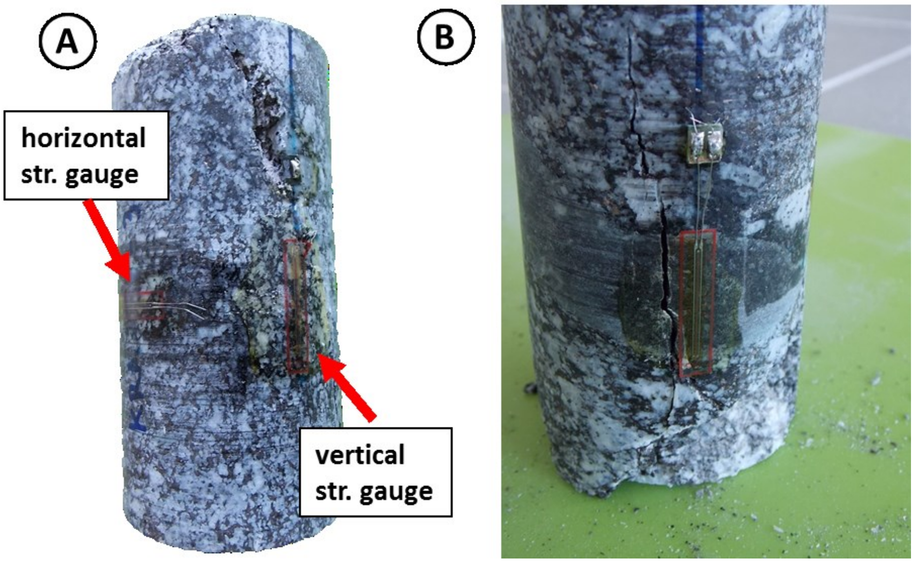

Fig. 4 A – example of syenite-dominant sample equipped with strain gauges after uniaxial compression test; B – detail of one vertical strain gauge on small part of enclave.

The triaxial compression testing was performed in a Hoek cell on a set of rock core specimens with a diameter of 38.1 mm and h/d ratio of 2.0 prepared from syenites (3 pcs), enclaves (3 pcs) and contacts between both petrographic types (2 pcs). The syenites and mafic microgranular enclaves were tested under three different confining pressures (5 MPa, 10 MPa and 20 MPa), whereas the samples containing contacts were tested under a constant confining pressure of 5 MPa. Some examples of each sample type after testing are displayed below (Fig. 5). The load rate of 0.5 MPa/s was applied for syenites, and a deformation rate of 1 μm/s was applied during the rest of triaxial tests.

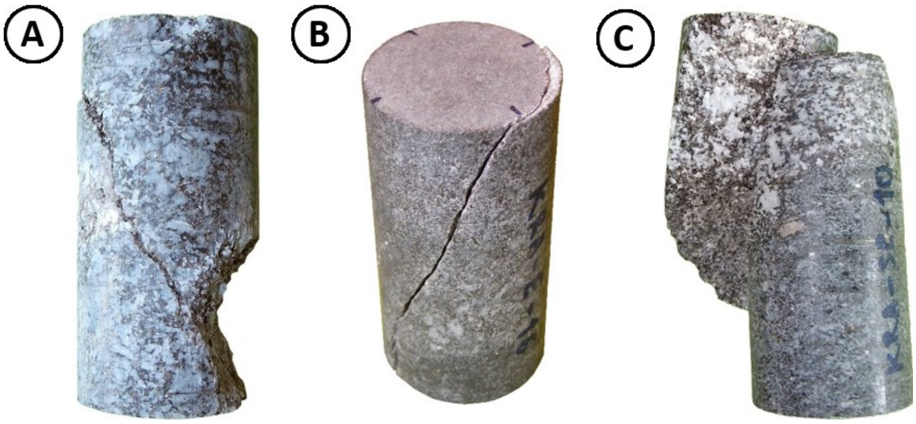

Fig. 5 Rock core specimens after triaxial compression tests. A – syenite; B – mafic microgranular enclave; C – contact between syenite and enclave.

4 RESULTS AND DISCUSSION

The density determinations carried out before the testing of strength properties indicate that the samples were composed of sufficiently fresh minerals and that mass-density variations between the individual samples were relatively minor (up to 1 %). In accordance with the higher abundance of mafic minerals, the enclaves show systematically higher mass-densities compared to the syenite hosts (Table 1). In addition, the mafic microgranular enclaves have rebound hardness values that are about 15 % higher than those of the associated syenites. The higher hardness of mafic microgranular enclaves is even more highlighted when the measured values are correlated to the uniaxial compressive strengths (Table 1). In contrast, the mafic microgranular enclaves show slightly lower values of indirect tensile strength in comparison with their host rocks. This contradictory behaviour is very probably related to the textural and mineralogical differences between enclaves and syenites. Enclaves are relatively fine-grained compact rocks and these features may be the cause of their higher hardness. On the other hand, enclaves are relatively enriched in flow-oriented mafic minerals (mica, amphibole) having perfect cleavage, a feature that may cause a reduction of enclave tensile strength properties compared to their host rocks.

Tab. 1 Mass-density [ρ], rebound hardness [R], correlated uniaxial compressive strength (UCS) and indirect tensile strengths [σt] of multicomponent geomaterials.

	Parameter	Syenite	Enclave
Mass density	ρ [kg/m^3]	2780	2810
	Standard deviation [kg/m^3]	±15	±20
	Variation [%]	0.5	0.7
Rebound hardness	R [-]	32	38
	UCS [MPa] (correlated)	59	89
Indirect tensile strength	σ_t [MPa]	9.4	8.9

The uniaxial and triaxial compressive strength properties of the tested multicomponent geomaterials are summarised in Table 2. A clear positive correlation between the increasing confining pressures (from 5 to 20 MPa) and the rock strength of both investigated petrographic types can be recognised. However, the mafic microgranular enclaves reach higher strengths (Fig. 6). The increasing positive strength effect associated with the presence of mafic microgranular enclaves is also visible during the testing of triaxial compressive strength of the syenite-enclave multicomponent samples (Figure 7; Table 2). The fact that the contacts between syenite and enclave do not represent zones of the predisposed weakening of mechanical properties is a further important result from the triaxial tests (Fig. 5C).

The obtained triaxial compressive strength properties are in line with our laboratory data for the uniaxial compressive strength testing of multicomponent geomaterials. The host syenites behave like "softer" rock types during the tests, whereas the mafic microgranular enclaves in multicomponent systems can be considered as "stress concentrators" (Fig. 8). This observation is fully compatible with pilot results of uniaxial

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compressive strength tests published for multicomponent geomaterials made of quartz-rich and quartz-poor rock composites. Absolute numbers, however, are hardly comparable with published data due to the different shapes and dimensions of the tested rock samples [6].

Differences in the values of Young's modulus between petrographic types have also practical meaning. The aggregate strength and stiffness influence the final properties of concrete, especially in high strength concrete classes. When the crushed rock with a high percentage of enclaves is used as aggregate in concrete, it could no longer be considered as homogenous material with properties of the host rock.

Tab. 2 Triaxial compressive strength (TCS), uniaxial compressive strength (UCS) and static elastic moduli of multicomponent geomaterials.

		Parameter	Syenite	Enclave
Triaxial compressive strength	$\sigma_3 = 5$ MPa	$\sigma_{1\,max}$ [MPa]	129	169
	$\sigma_3 = 10$ MPa	$\sigma_{1\,max}$ [MPa]	165	210
	$\sigma_3 = 20$ MPa	$\sigma_{1\,max}$ [MPa]	222	248
TCS - contact syenite/enclave	$\sigma_3 = 5$ MPa	$\sigma_{1\,max}$ [MPa]	131	
	$\sigma_3 = 5$ MPa	$\sigma_{1\,max}$ [MPa]	137	
Uniaxial compressive strength	UCS	σ_c [MPa]	99	126
	Young's modulus	E [GPa]	34	61
	Poisson ratio	ν [-]	0,22	0.21

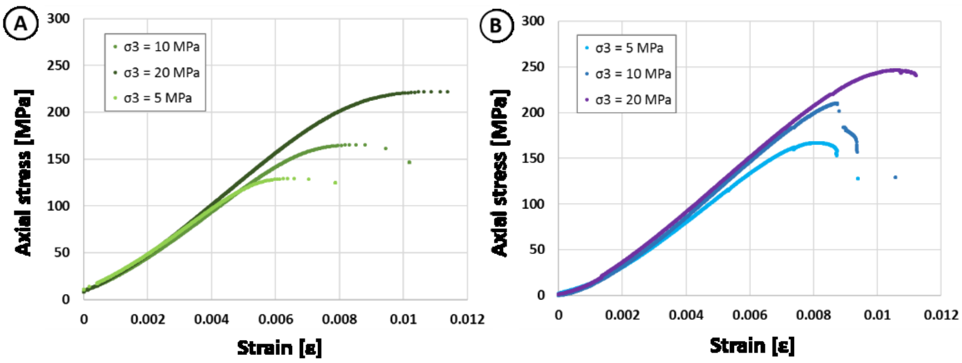

Fig. 6 Stress-strain diagrams for triaxial compressive tests. A – an example of deformation curves for syenites; B – an example of deformation curves for enclaves.

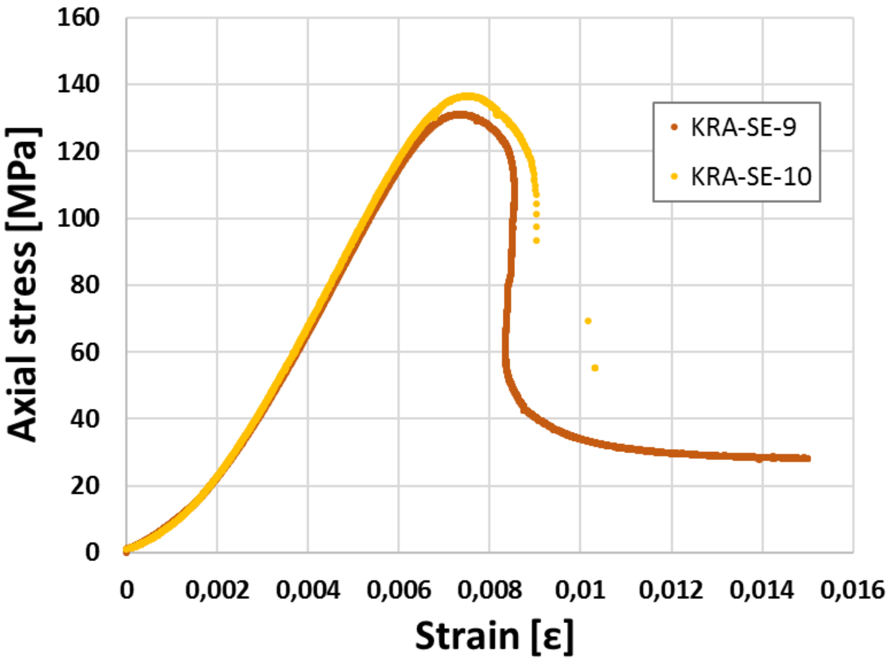

Fig. 7 Stress-strain diagrams for triaxial compressive tests of two syenite-enclave multicomponent samples during triaxial tests under 5 MPa confining pressure.

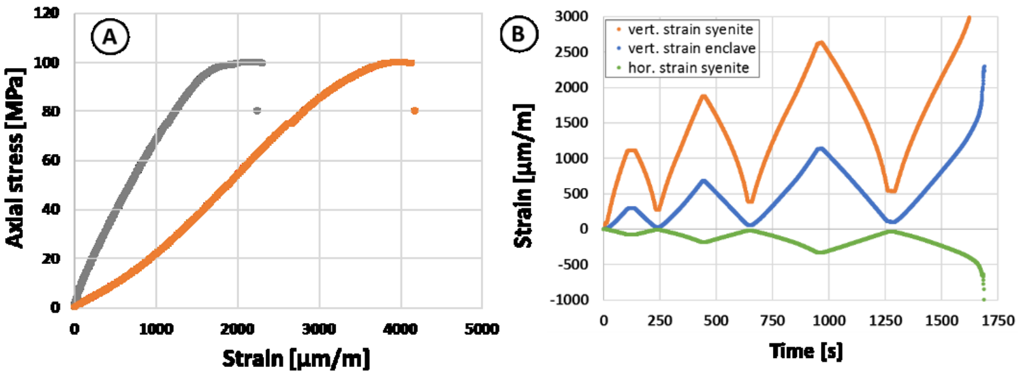

Fig. 8 Results for sample equipped with one vertical strain gauge on syenite and one on enclave; A – stress-strain diagram for uniaxial loading (grey – enclave, orange – syenite); B – different stiffness of syenite-enclave components during cyclic loading.

5 CONCLUSIONS

Based on the combined testing of strength properties (including also the first published results for triaxial compressive strength) of multicomponent geomaterials from quartz-poor (syenitic) systems, our study obtains the following results:

(1) Mafic microgranular enclaves enclosed in syenitic rocks and even the contact zones between the enclaves and host rocks do not have any negative influence on the rock strength in case of its uniaxial and triaxial compressive strength properties.

(2) Mafic microgranular enclaves behave during the testing of uniaxial and triaxial compressive strength properties as “stress concentrators” within the multicomponent enclave-syenite system. This is related to a relatively fine-grained character of the mafic microgranular enclaves compared to the host syenites.

(3) In contrast to the obtained compressive strength properties, the mafic microgranular enclaves are relatively enriched in flow-oriented mafic minerals (mica, amphibole) having perfect cleavage, a feature that may cause a negligible reduction of enclave tensile strength properties compared to their host rocks.

(4) The presented results are based exclusively on the multicomponent materials from quartz-poor (syenitic) rocks at one representative locality and should be verified by future studies focused on the behaviour of such geocomposites from various rock systems.

Acknowledgements

This paper has been worked out under the project No. LO1408 “AdMaS UP - Advanced Materials, Structures and Technologies”, supported by the Ministry of Education, Youth and Sports under the “National Sustainability Programme I”.

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